AVR adjustment of Synchronous Generators in Weak Grids under Faulty Conditions.

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I. Introduction

In weak grids, all the generator units are usually connected to the same bar, so an eventually fault affects all generators. In addition, for being a weak grid, it is extremely important to adjust correctly the excitation system[2]. In this way it is possible to carry out a careful protection system adjustment [3].

It is taken as an example of weak grid an electric island located in the North of Africa. This electric island is a small city that produces its own energy using seven diesel groups connected to the same bar.

In this system, as all groups are connected to the same bar, if eventually a fault occurs, the voltage would fall down. Therefore, the generators excitation systems would not have enough voltage to excite generation machines. In weak grids, when a fault occurs, voltage falls abruptly , what is usually called voltage gap. These voltage gaps are stronger when the grid is weaker.

In order to ensure the power supply, it is necessary to provide current to the fault to find the exact location of it. Furthermore, a sufficient level of current has to be provided during, at least, the time necessary to allow the protections act. For this purpose, compounding systems that provide voltage supply to the excitation systems (Automatic Voltage Regulator, AVR) during the fault are installed.

In the weak grid of the example some problems with voltage stability happens, so it is important to study groups excitation systems. The aim of the research developed is to study the optimal AVR adjustment which improves the response in case of fault in weak grids [4]. For this purpose an experimental bench was designed and sucessives faults were carried out in order to obtain the voltage evolution considering different adjustments.

Finally, the results of the laboratory test are shown, with the aim of deducing the conclussions that provide empirical experience facing that critical situation described above.

II. System Description

The extrapeninsular electrical system of Ceuta is an isolated small electrical system based on a radial layout from the bar of the power plant, Figue 1.

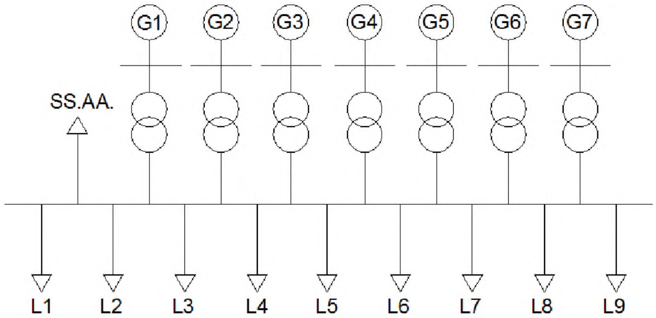

Figure 1. Electrical system scheme of Ceuta.

Due to the system topology an occasional fault in any of the distribution lines involves a voltage gap more severe than in a conventional system.

The power plant has seven generation groups (whose maximum power capacity vary between 6 and 12.3 MW), moved by diesel motors (Table 1).

TABLE I. ELECTRICAL DATA OF THE EXAMPLE SYSTEM.

	Low load P.Gen (MW)	**Peak-load P.Gen (MW)**	**Pmax (MW)**	**H(s)**
GR1	4	3	5.8	2.114
GR2	0	3	5.8	2.114
GR3	4	3.5	5.8	1.429
GR4	0	4.5	6.7	1.440
GR5	0	7	9.5	1.381
GR6	11.5	10	12.3	1.918
GR7	0	5	12.3	2.051
Total	19.5	36	58.2	

The substation consists of a single 15 kV bar where nine distribution lines start. Auxiliary services of the plant are also fidded from this single bar.

In the example grid large disturbances happened in voltage caused by faults in distribution system. These disturbances forced to disconnect some groups of the system and caused load shedding [5].

In the paper presented below it is studied how to optimize AVR adjustments under fault. Afterwards, it will be studied how to optimize the coordination of different groups as well as protection system.

Endesa Generación S.A. (electrical company) worked with authors to carry out the study of excitation systems and right coordination with protection system.

III. AVR Topology

The principle of a voltage regulator is based on a PID regulator that acts on the setpoint voltage error and the real one, Figure 2.

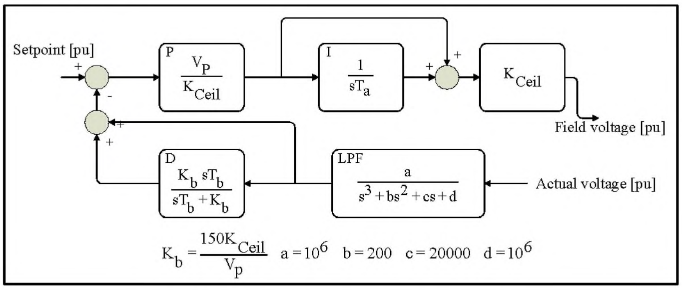

Figure 2. Transfer function of AVR used.

To the main regulation block represented by a PID (that can be real or simplified) other regulation loops are added defined by the operation mode[6]. Those operation modes are translated into a ideal regulator setpoint, so the setpoint value will be obtained using the active operation mode in each case.

Finally, limiters in most comercial AVR must be considered. Those limiters are implemented as blocks with saturation of regulator output signal.

Usually, AVR adjustment is made in two steps. First of all, no-load regulator transfer function is adjusted by setpoint leaps without load. Afterwards, tests called load rejections are made. These tests consists of increase the reactive power that the machine generates and open the group switch, so regulator answer against an abrupt contingency is shown [7, 8].

The paper presented below evaluates if conventional adjustment method is adequate for weak grids. It also evaluates if AVR behaves properly facing faults whit the obtained adjustment [9,10].

In order to change the performance of the regulator gain, values of proportional (V_p), integral (T_a) and derivative (T_b) performance have been modified.

IV. Experimental Bench

In order to carry out the study explained in this paper an experimental bench that simulates a group of a real plant has been designed and built.

The machine installed in this bench is equipped whith double excitation. It is a generator with indirect excitation that, supplementary has slip-rings making possible the static excitation. In this way, the study presented can be carried out. For this reason different excitation data (double excitation) is shown in the machine data plate (Table 2).

TABLE II. Synchronous Machine Data Plate.

	10EXR-132ME1.4			
Sn (kVA)	5	cos Phi	0.8
Phases	3	Frequency (Hz)	50
Speed (rpm)	1500	Nominal Voltage (V)	400/231
IP	21	Nominal Current (A)	7.2
Excitación (Brushless/Static)			
U_{exc} (V)	33/45	I_{exc} (A)	0.65/4.1

As a motor machine of the group an asinchronous machine has been installed. It has the same number of poles than the generator installed. This asinchronous machine is moved by a frequency converter that allows varying the group speed and making possible to couple the generator to the network in sinchronous conditions.

To simulate the electrical scheme of a real group it has been implemented a bench that represents faithfully the electrical scheme of a plant. It includes two protection relays MICOM P345 and P343 and a control cabinet with wired logic that simulates the control panel of a plant, Figure 3.

The electric scheme of the assembly is shown in Figure 4.

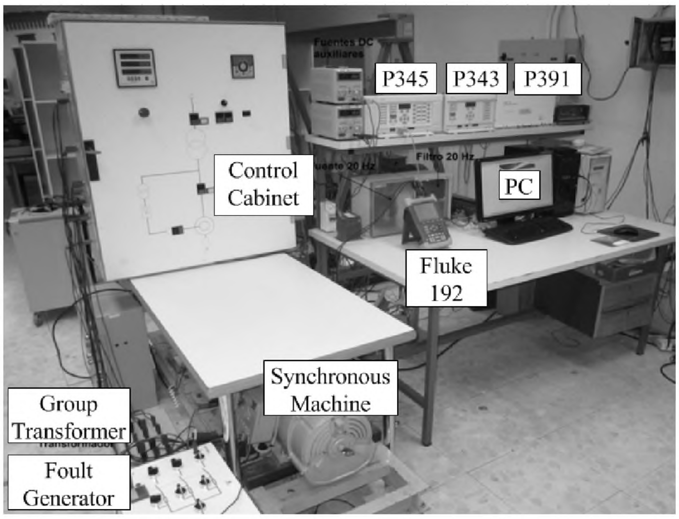

Figure 3. Laboratory test bench.

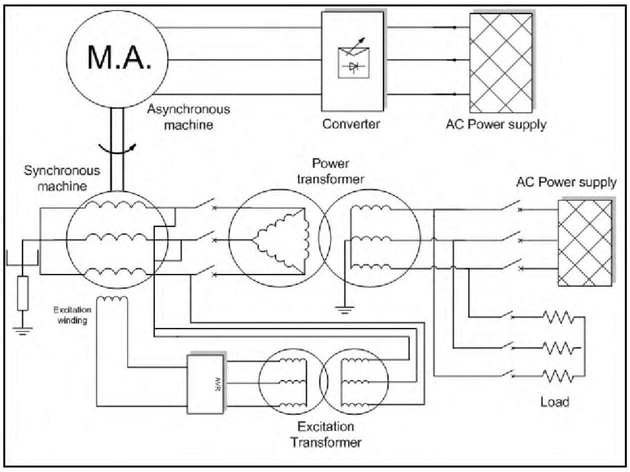

Figure 4. Laboratory test bench scheme.

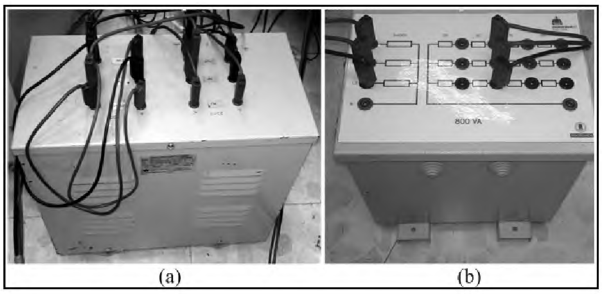

Figure 5. (a) Power transformer 1:1 Yd11, (b) Excitation transformer.

In the bench it have been implemented the same protection functions that exist in the real group of study, setting the same adjustments so that group performance against different test can be evidenced.

With the objetive of generate faults on the generator terminals or in the high voltage transformer side a transformer of Yd11 group and a transformation ratio of 400:400 V has been installed, Figure 5 (a).

To simulate the excitation system it has been used a three-phase transformer with taps that has a transformation ratio of 400:100/75/50/25 V. In this way, peak voltage of the regulator can be adapted changing the tap of the excitation transformer, Figure 5 (b).

Voltage provided by the excitation transformer is used to supply the regulator. This voltage is rectified by means of a diod bridge inside the AVR. The voltage regulator installed is Unitrol 1000-15 from ABB. The AVR regulates direct current bus voltage using an IGBT that chops the signal, so it regulates the excitation voltage provided to the circuit. The maximum current provided to the circuit is 15A.

It has been introduced the same limit values as in the real group of the example grid, so the experimental results are representative.

The laboratory test bench is complemented with a faults generator. It allows selecting the type of fault wanted and program the length of the fault by a timer. It also allows generating dead shorts or through 22 Ω resistor. In Figure 6 the connection scheme is shown.

V. EXPERIMENTAL RESULTS

Tests carried out try to compare the answer of the voltage signal facing the same fault using different PID adjustments [11].

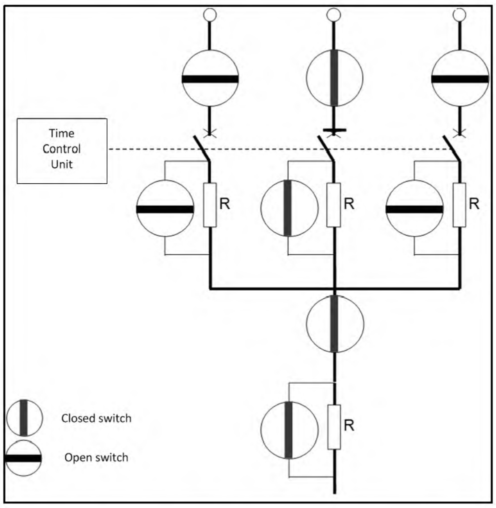

Figure 6. Faults controlled generator.

For this purpose, a number of tests with the same type of fault and with the same lenght were programed, and successive short-circuits with different adjustments were done to verify the performance of the generator against a short-circuit.

The generator can be excited both static or brushless, so it is done the same study for the same generator but using two different excitation ways, static and brushless.

It is executed an study of PID perfonmance against a short-circuit near to the machine. In order to carry out this study the laboratory bench is configurated in such way that the machine is connected through a power transformer to a bar where a pure resistive load is connected. The machine generates 1.2 kW (30% P_n aproximately) and works with a reduced voltage of 236.3 V (59% U_n), so mechanical stress stand by the machine during the fault is reduced. Successive three-phase short-circuits of 500 ms will be done in the high voltage side of the power transformer.

A. *Static excitation.*

Since voltage regulator responds to a PID transfer function, proportional, derivative and integral actions are changed starting from ideal adjustments obtained no-load and with load rejection.

TABLE III. LOAD OPTIMAL ADJUSTMENTS, STATIC EXCITATION.

P (V_p)	**I (T_a)**	**D (T_b)**
3.5	0.1	0.2

First of all, tests in proportional action are made increasing gain until overoscillation is as high as become unacceptable.

As it is shown in Figure 7, during the fault, voltage signal remains aproximately in the same value independently of the proportional gain value selected. After eliminating the fault, it is observed that the more proportional gain is increased the more rise time and amplitude are reduced. Therefore, the voltage of the machine comes back faster to its steady state value. In other words, the machine's answer under a fault in terminals is better if proportional gain value is increased compared to its ideal value obtained no-load.

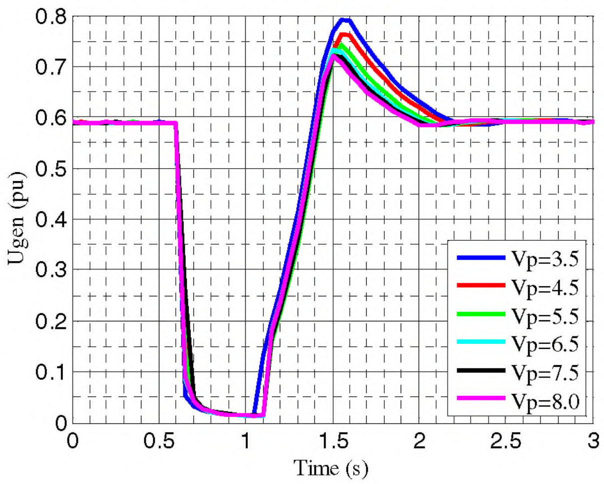

Figure 7. Sensitivity to V_p, static excitation.

Starting from ideal adjustments no-load, integral gain (I) is increased, test after test, in order to evaluate its general impact on AVR answer under fault.

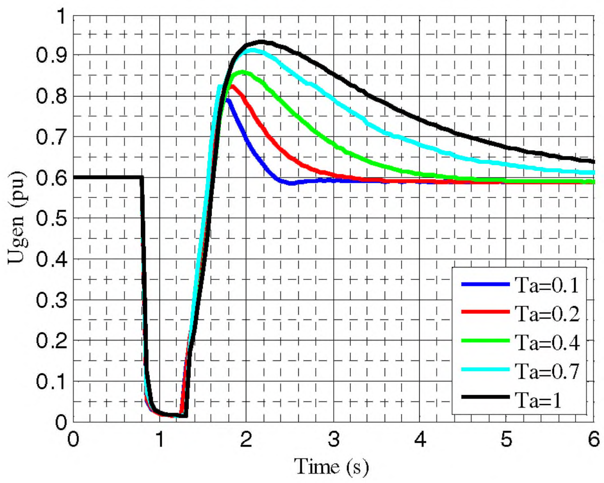

Figure 8. Sensitivity to T_a, static excitation.

As Figure 8 shows, during the short-circuit, voltage mantains aproximatly its value independently of the integral gain value chosen. After eliminating the fault, it is shown that the more integral gain increases the more peak value increases and, above all, the more time the generator takes to come back to its steady state value. In other words, the machine´s answer under a fault is worse if the integral gain value increases compared to its ideal value obtained no-load and load rejection.

Starting from ideal adjustments no-load, derivative gain (D) is increased, test after test, in order to evaluate its general impact on AVR answer under fault.

As is shown in Figure 9, during the fault, voltage signal remains aproximately in the same value independently of the derivative gain value selected. After eliminating the fault, it is observed that the more proportional gain is increased the more peak value increases and the part of the signal called "undershoot" is accentuated slightly before coming back to its steady state value. In other words, the machine´s answer under a fault is worse if the derivative gain value increases compared to its ideal value obtained no-load.

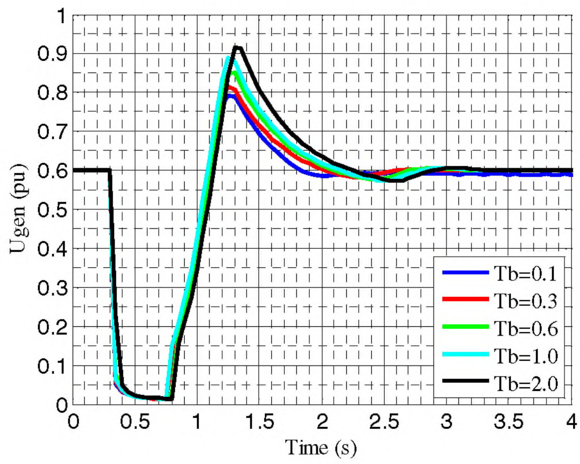

Figure 9. Sensitivity to T_b, static excitation.

B. Brushless excitation.

Since voltage regulator responds to a PID transfer function, proportional, derivative and integral actions are changed starting from ideal adjustments obtained no-load.

TABLE IV. LOAD OPTIMAL ADJUSTMENTS, BRUSHLESS EXCITATION.

P (V_p)	I (T_a)	D (T_b)
1.0	0.12	0.08

Following the same method as static excitation, proportional action gain values will be modified.

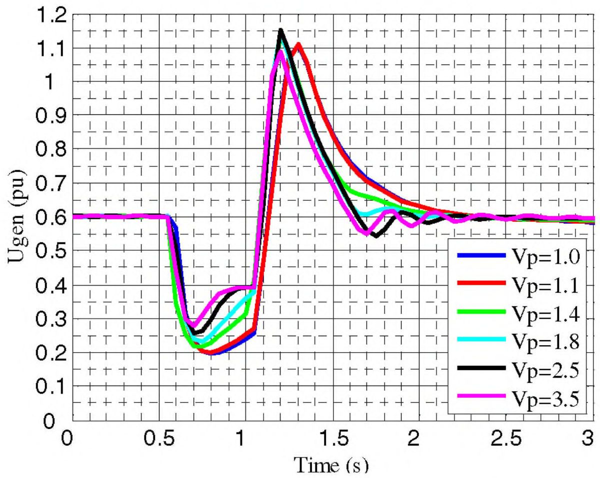

Figure 10. Sensitivity to V_p, brushless excitation.

It is shown that increasing proportional gain, terminal voltage of generator increases during the fault. After the fault clearance, the rise in proportional gain decreases rising time to voltage peak value. Hence, generator voltage come back sooner to its steady state value, Figure 10.

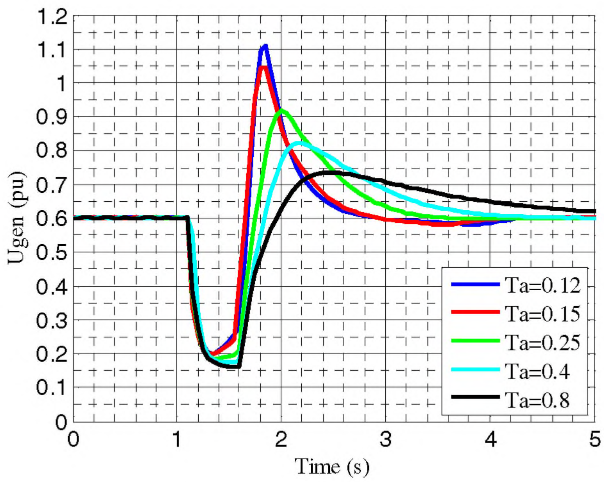

Figure 11. Sensitivity to T_a, brushless excitation.

Altering AVR integral gain from ideal value no-load, the tendency of the answer is obtained.

When integral gain value is modified, light differences appear in generator terminal voltage during the fault. Nevertheless, the most remarkable effect is shown after the fault clearance. The more integral gain is increased the less voltage peak value and the generator takes longer to come back to its stady state voltage value, Figure 11.

In the same way it was done with static excitation, starting from ideal adjustments no-load, derivative gain (D) is increased, test after test, in order to evaluate its general impact on AVR answer under fault.

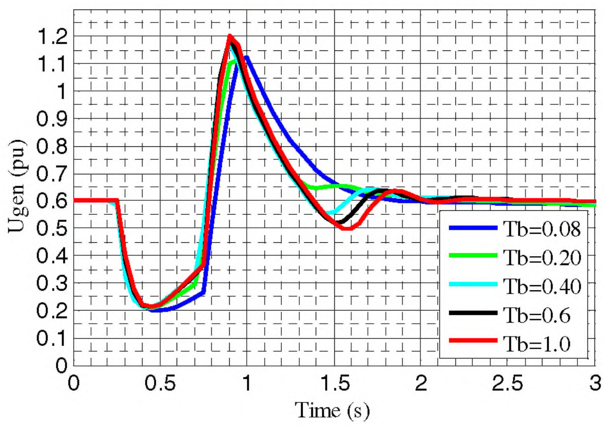

Figure 12. Sensitivity to T_b, brushless excitation.

In general terms, derivative gain effect is the less noticeable. In the same way as integral gain, when derivative gain value is modified, light differences appear in generator terminal voltage during the fault. Its impact is slightly higher after the fault clearance, when it is shown that the more derivative gain is increased the more the overshoot is also increased, Figure 12.

VI. CONCLUSIONS

It can be concluded that PID parameters have, obviously, a direct impact on generator´s answer under a short-circuit. Modifying these parameters the answer can be eventually optimized, increasing the current supplied to the fault, decreasing the overshoot and reducing the time necessary to come back to the value it had before the fault. But it is true that when PID parameters are modifyed in order to optimize group´s answer under fault, these PID values deviates from their ideal values no-load. Therefore, to favor the adjustments in order to optimize the answer under short-circuit will automatically involve to degrade its answer under command leaps (no-load adjustments and load rejection).

As traditional adjustments answer reasonably under short-circuit and it is difficult to obtain ideal parameters under fault in a real plant, it is concluded that conventional AVR adjustment is enough under a short-circuit situation.

The study stage of the excitation system under short-circuit shows interesting conclusions about optimization under short-circuit. However, the study should continue facing two groups with similar power with the aim of notice the system performance when AVR adjustment change.

ACKNOWLEDGMENT

Authors wish to thank the support received from "Studies and Protections Department" of Endesa Generación S.A., José Ángel Martínez from ALSTOM Hydro España S.L and Juan Carlos Larrañaga from Asea Brown Boveri S.A.